# *PREDICTING OF LAND COVER CHANGES UNTIL 2030 AND ASSESSING SUSTAINABILITY STATUS IN THE MANDEH REGION, INDONESIA*

***FEBRIANDI* [1*], *Siti FATIMAH* [2], *TRIYATNO* [1], *Dedi HERMON* [1], *Aprizon PUTRA* [3], *Herdiana MUTMAINAH* [4], *Taslim ARIFIN* [3], *Rudhy AKHWADY* [3]**

DOI: 10.21163/GT_2025.201.18

**ABSTRACT**

This study aims to analyze land cover dynamics and evaluate the sustainability status of marine tourism in the Mandeh region. Despite its significant tourism potential, the region faces ecological and socio-economic challenges. This research integrates land cover change analysis with sustainability assessments to provide a foundation for policy recommendations and strategic development approaches. A descriptive research approach was employed, incorporating both qualitative and quantitative methods. Qualitative data were gathered through field observations, while quantitative data were analyzed using remote sensing to assess land cover changes and sustainability status. The study applied purposive sampling for data selection and utilized supervised classification with the Maximum Likelihood method to analyze land cover changes. Additionally, the Multi-Dimensional Scaling (MDS) method, specifically the Rapid Appraisal of the Mandeh Region (Rap-MR), was used to evaluate sustainability across economic, social, and environmental dimensions. The results indicate significant land cover transformations in the Mandeh region from 2020 to 2030. Water Bodies (WB) remain dominant but exhibit a slight decline due to sedimentation and climate change. Secondary Forest (SF) and Primary Forest (PF) are expected to decrease, mainly due to agricultural expansion and infrastructure development. Mangroves (Ms) and Mixed Gardens (MG) are also projected to shrink, reflecting conservation challenges. Conversely, Built-up Land (BuL) and Palm Plantations (PP) are anticipated to expand, driven by tourism and economic growth. Land cover classification achieved high accuracy, with an overall accuracy rate exceeding 87%. The sustainability analysis highlights economic benefits from tourism but reveals conflicts in resource utilization. The economic dimension shows a need for infrastructure investment and revenue optimization, while the social dimension emphasizes education and disaster preparedness. The environmental dimension calls for stricter conservation policies and land-use planning. In conclusion, the Mandeh region requires a balanced approach to development, integrating economic growth with environmental sustainability. Policy interventions should focus on reforestation, controlled urban expansion, and sustainable tourism management to ensure long-term ecological and socio-economic stability.

***Key-words:*** *Land cover, Sustainability, Marine tourism, Multi-dimensional scaling, Mandeh region.*

## 1. INTRODUCTION

Indonesia's coastal and marine regions possess significant potential for diverse marine tourism activities due to their status as the center of the Coral Triangle, which harbors exceptionally high marine biodiversity (Hidayah et al., 2024; Watt-Pringle et al., 2024).

------------------------------

[1]*Department of Geography, Universitas Negeri, Padang-Indonesia. (F) andi_geografi@fis.unp.ac.id, (T) triyatno@fis.unp.ac.id, (DH) dedi.hermon@fis.unp.ac.id*
[2]*Department of History Education, Universitas, Padang-Indonesia. (SF) sitifatimah@fis.unp.ac.id*
[3]*National Research and Innovation Agency, Cibinong-Bogor, Indonesia. (AP) apri024@brin.go.id, (TA) tasl003@brin.go.id, (RA) rudh002@brin.go.id*
[4]*National Research and Innovation Agency, Sukolilo-Surabaya, Indonesia. (HM) herd005@brin.go.id*
[*]*Corresponding author email: andi_geografi@fis.unp.ac.id*

Nevertheless, the management and governance of marine tourism remain suboptimal. Despite these challenges, a study by Bahar (2023) indicates that the number of tourist arrivals and foreign exchange revenues generated by the marine tourism sector have shown a consistent upward trend. However, the overall development of Indonesia's marine tourism industry remains significantly underutilized. Comparatively, Indonesia's marine tourism performance lags behind that of neighboring countries with smaller marine tourism potential, such as Singapore, Malaysia, Thailand, and Australia. This disparity in performance has led to economic stagnation for local communities in marine tourism areas, as many remain economically disadvantaged. Additionally, several coastal and marine ecosystems, which serve as key marine tourism attractions, are experiencing degradation and ecological disturbances.

The Mandeh region, located in Pesisir Selatan Regency, West Sumatra Province, Indonesia, is recognized as a marine tourism destination with substantial potential for further development (Putra et al., 2024). This region was officially designated as a priority marine tourism attraction in Indonesia under the National Tourism Development Master Plan (NTDMP) in 2004 (Wilis et al., 2020; Hermon et al., 2022). In line with this designation, the local government of Pesisir Selatan Regency and the West Sumatra Provincial Government have actively encouraged the expansion of marine tourism, complementing the traditional fishing activities of local communities. To support this initiative, it is crucial to enhance community engagement in marine tourism development while ensuring environmental conservation. However, the region's mangrove forest ecosystem has experienced significant degradation. Since 2016, approximately 480 $m^2$ of mangrove forest has been encroached upon, and by the end of February 2017, the affected area had expanded to 1,230 $m^2$ (Raynaldo et al., 2020). Moreover, only 15–20% of the 7,000 ha of coral reefs in the Mandeh region remain in good condition. This degradation is primarily attributed to destructive fishing practices, including the use of toxic substances, explosives, and trawling, as well as excessive sedimentation from river discharge (Zakaria et al., 2021). Such environmental degradation necessitates immediate and comprehensive intervention from all stakeholders, particularly the government, to ensure the sustainability of marine tourism in the region.

The development of the Mandeh region as a marine tourism destination must be strategically implemented by optimizing its natural resource potential, including capture fisheries, aquaculture, agriculture, and local craft industries. Economic expansion in this sector should be integrated with conservation efforts aimed at preserving coastal ecosystems, particularly coral reefs and mangrove forests, which serve as key ecological and economic assets for both tourism and fisheries. Sustainably enhancing economic activities will contribute to improving the livelihoods of local communities. As community welfare improves, there is a corresponding positive impact on the quality of residential environments and greater local participation in tourism development. To ensure long-term benefits, the development framework must be carefully designed to maximize economic benefits for local communities while safeguarding environmental integrity. A misguided development approach could lead to irreversible negative consequences on economic sustainability, physical environmental conditions, and the region's socio-cultural fabric. Therefore, a well-defined Regional Spatial Planning (RSP) strategy is essential, encompassing regional zoning, environmental protection measures, settlement area delineation, and tourism infrastructure planning (Cuevas-Wizner et al., 2024). These zoning regulations should be designed to balance economic activities with ecological preservation, ensuring the sustainable development of the Mandeh region as a premier marine tourism destination (Smith et al., 2011; Papageorgiou, 2016; Jinzhu et al., 2014).

Over the last 10 years, several strategic developments have been implemented in the Mandeh region to enhance its tourism potential while ensuring sustainability. In 2015, the region was officially designated as the Mandeh Integrated Marine Tourism Area, leading to the construction of key infrastructure, such as the 43 km Mandeh ring road, which significantly improved accessibility (Fatimah et al., 2021). Subsequent developments included the construction of tourism piers in 2016, the expansion of mangrove conservation areas in 2017, and the establishment of local policies to regulate tourism zoning and environmental management in 2018 (Syam, 2018). Community-based tourism programs were also initiated in 2019, equipping local communities with the necessary skills to participate in the growing tourism industry. Further enhancements included the development of resorts and accommodations in 2020, the establishment of the Special Economic Zone (SEZ) for tourism in 2021, and the revitalization of supporting facilities such as trekking routes, sports centers, and coastal tourism amenities in 2022. Promotional efforts, including digital campaigns and cultural festivals, were intensified in 2023 to increase visitor engagement and economic benefits for the local communities (Ansharullah & Natasha, 2020). These developments demonstrate a concerted effort to position Mandeh as a leading marine tourism destination while prioritizing ecological conservation and community empowerment. A community-centered development approach should be prioritized to foster local engagement and ensure that policies align with the needs of the local population. It is crucial to formulate policies that support the advancement of sustainable marine tourism by integrating economic progress, social stability, and ecological preservation.

Overall, Indonesia's coastal and marine regions particularly the Mandeh area in the western part of Sumatra Island possess immense potential for marine tourism development. However, this development must be meticulously planned and executed by sustainability principles to maximize long-term socio-economic benefits for local communities while safeguarding marine and terrestrial ecosystems. This study aims to analyze land cover dynamics and evaluate the sustainability status of marine tourism in the Mandeh region. The novelty of this research lies in its focused exploration of the Mandeh region, which, despite its substantial tourism potential, faces pressing ecological and socio-economic challenges. This study integrates land cover change analysis with sustainability assessments to serve as a foundation for formulating policy recommendations and strategic approaches for sustainable development management.

## 2. DATA AND METHODS

### 2.1. Study location

This study was conducted in the Mandeh region, which is geographically positioned at 01°11'05" South Latitude and 100°26'55" East Longitude. This area falls within Koto XI Tarusan Sub-district, Pesisir Selatan Regency. The Mandeh region and its surrounding areas form a naturally sheltered bay, protecting the strong waves and currents of the Indian Ocean. The total area of the region spans approx ±18000 ha (Raynaldo et al., 2020; Alhadi et al., 2023), encompassing six villages and several nearby small islands. The coastline of the Mandeh region extends to 79.24 km in total, with 45.06 km situated along mainland Sumatra and approximately 34.18 km surrounding the small islands. For more details, the map of study location can be seen in **Figure 1** below.

### 2.2. Research Types

This study employs a descriptive research approach, aiming to characterize the study area through the use of quantitative data which integrates both qualitative and quantitative research techniques (Brown et al., 2017; Duggan et al., 2024). According to Bakus (2007), the combines quantitative and qualitative methodologies to enhance the comprehensiveness, validity, reliability, and objectivity of research findings. In this study, qualitative data were collected through direct field observations, while quantitative data were analyzed to assess land cover changes using remote sensing data and to evaluate the sustainability status of the region.

The sampling technique employed in this study is purposive sampling, which involves selecting samples that are deemed representative of the population (Prarikeslan et al., 2019; Hermon et al., 2020). To analyze land cover changes, an accuracy assessment was conducted using a random sampling approach on selected samples within the study area. The primary objective of this assessment was to evaluate the classification accuracy, ensure the reliability of the derived data for further analysis, and minimize potential errors associated with the "Garbage In, Garbage Out" (GIGO) principle (Lilimu, 2023). The sample dataset in this study consists of all pixels derived from land cover change analysis. The sampling framework was determined based on the number of pixels selected from the relevant study area.

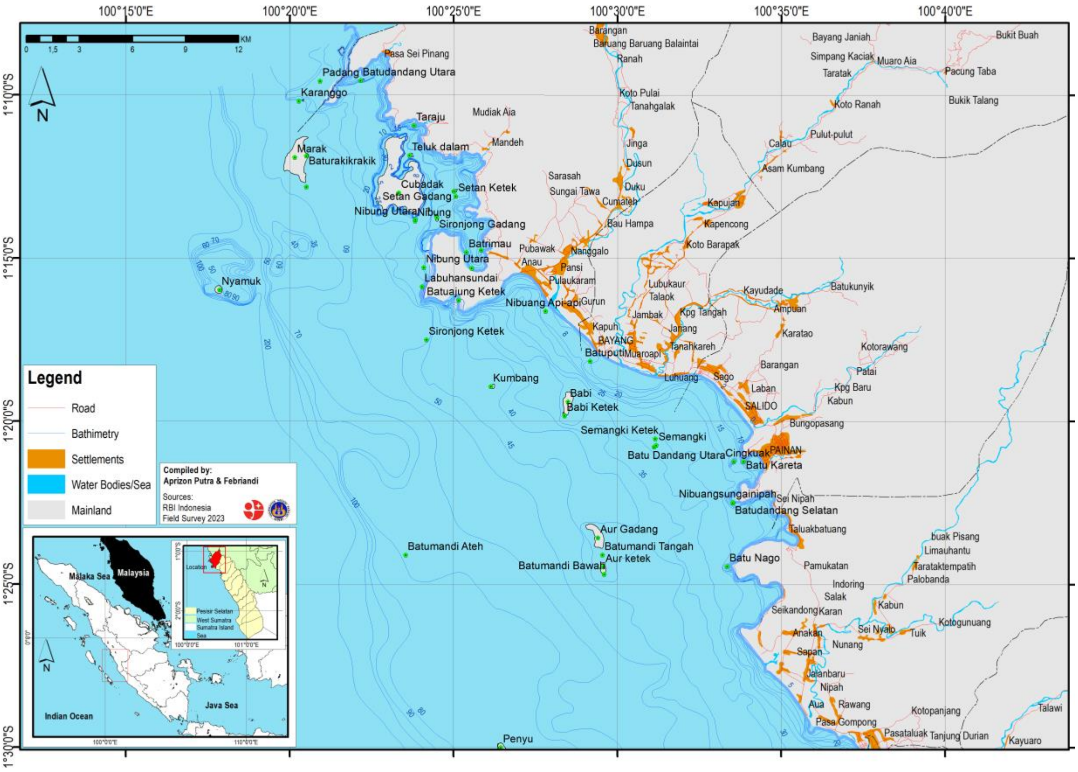


**Fig. 1.** Map of the study location.

The appropriate sample size was calculated using the following formula (Arif et al., 2023; Darem et al., 2023; Binarti & Santoso, 2024).

$$n = N/(1 + (N \times e^2)) \quad (1)$$

where: $n$ = number of samples; $N$ = number of populations (pixels); $e$ = precision.

To determine the number of samples based on the land cover changes class, the following formula is used (Costea & Haidu, 2010; Arif et a., 2023; Darem et al., 2023).

$$ni = \frac{Ni}{N} * n \quad (2)$$

where: $ni$ = number of sample members by class; $Ni$ = number of population members by class; $N$ = total population size; $n$ = the total number of study location samples.

## 2.3. Data Analysis Technique

### *2.3.1. Land Change Modeller (LM)*

This study employs Supervised Classification using the Maximum Likelihood (ML) method to analyze land cover changes in the Mandeh region. ML is a statistical approach utilized to determine the spatial distribution of various land cover classes (Haris et al., 2021; Darem et al., 2023; Putra et al., 2023). Through this classification, it is expected to identify distinct land cover categories, including WB, PF, SF, MG, P/B, BuL, Ms, RF, and PP. The classified land cover change results will then be further analyzed using the Markov Change Model (Costea & Haidu, 2010; Zhang et al., 2023; Hussain et al., 2024).

The study process consists of three main stages preparation, analysis, and interpretation. 1) During the preparation phase, activities include conducting a literature review, collecting Landsat satellite data, and obtaining thematic maps relevant to the study location; 2) The analysis stage involves several key steps, namely geometric and radiometric rectification of satellite images, supervised classification, and identification of driving forces that influence land cover change; Furthermore, 3) Land cover change predictions are generated using ARC-GIS software. The interpretation phase focuses on identifying trends in land cover transformation and conducting accuracy assessments.

The datasets used for land cover change analysis include Enhanced Thematic Mapper (ETM) 5 (2000), Landsat Enhanced Thematic Mapper Plus (ETM+) 7 (2009), Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (2019), and the map of Rupa Bumi Indonesia (RBI) from the Geospatial Information Agency (BIG), which serves as the base map for this study. This analysis requires converting the Digital Number (DN) values into reflectance values through radiometric correction of the Landsat imagery (Furtună et al., 2016; Pons et al., 2014; Czapla-Myers et al., 2024), following the standard formulation presented below.

$$\rho\lambda = (M\rho * Q_{cal} + A\rho)/Sin\ (\theta) \qquad (3)$$

where: $\rho\lambda$ = top of atmosphere reflectance; $M\rho$ = multi_band n reflectance value for each channel, which is known from metadata; $A\rho$ = value reflectance add_band $n$ any channel known from the metadata; $Q_{cal}$ = value DN; $\theta$ = value of the sun's elevation angle obtained from the metadata.

For determine the model of land cover the Marcov Chain_cellular Automata model using the assumption that land cover changes for the future $x_t$ + 1, at that time (t + 1) depends on the current condition expressed by $x_t$. For the land cover transition matrix, the formulation proposed by Benito et al. (2010); Paul et al. (2018) is used as follows.

$$x_{t+1} = x_t * p \qquad (4)$$

where: $p$ = the m*m matrix which indicates the number of pixels (such as the number of land cover classes), $p$ = a pair of land cover classes, $i$ and $j$, which can be expressed as follows.

$$p = (pij) = \begin{matrix} p_{11} & p_{12\ldots} & p_{1n} \\ p_{21} & p_{22\ldots} & p_{2n} \\ p_{n1} & p_{n2\ldots} & p_{nn} \end{matrix} \qquad (5)$$

Based on the formulation above, to determine the transition matrix for changes in land cover in the research area it can be written as follows.

$$p_{(n)} = p_{(n-1)}\ pij \qquad (6)$$

where: $P_{(n)}$ = land cover; $p_{(n-1)}$ = prediction of change; and $pij$ = transition matrix.

To determine the quality of the land cover changes, it is necessary to carry out an accuracy test which functions to see the quality of the model that has been produced using overall accuracy, user accuracy, and producer accuracy using the formulation proposed by Dash et al. (2023) as follows.

$$Users\ accuracy = \frac{xii}{x+1} * 100\% \qquad (7)$$

$$Produser\ accuracy = \frac{xii}{xi+} * 100\% \qquad (8)$$

$$overall\ accuracy = \frac{\sum xii}{N} * 100\% \quad (9)$$

where: $xii$ = diagonal value of the contingency matrix of the i-th row and the i-i pool; $xi$ = number of pixels in row i; $x + 1$ = number of pixels in the ith column; and $N$ = number of sample pixels.

*2.3.2. Multi-Dimensional Scaling (MDS)*

The analysis method applied in this study is Multi-Dimensional Scaling (MDS), utilizing the Rapid Appraisal of the Mandeh Region (Rap-MR) approach. This technique is an adaptation of the Rapid Appraisal for Fisheries (RAPFISH), which is designed to assess the sustainability status of marine tourism in the Mandeh region using a multidimensional framework (Fauzi & Anna, 2002). Rap-MR serves to simplify complex multidimensional data into a more structured and interpretable format. The Rap-MR analytical process comprises several key stages: 1) Identifying relevant attributes across dimensions that influence sustainability; 2) Assigning scores to each attribute based on sustainability criteria for the respective dimensions; 3) Applying the MDS method to evaluate the coordination and tension values associated with each attribute; 4) Assessing the sustainability index and status both multidimensionally and within each dimension; 5) Conducting a leverage analysis to identify key variables that significantly impact sustainability; and 6) Incorporating uncertainty analysis to ensure the reliability and robustness of the findings. The determination and evaluation of attributes are based on direct field observations and secondary data sources. The specific dimensions and attributes analyzed for assessing sustainability in the Mandeh region are summarized in **Table 1** below.

**Table 1.**

**Dimensions and attributes of sustainability status of marine tourism.**

| Dimensions | Attributes |
|---|---|
| Economy | Regional Income [RI]; Job Opportunities [JO]; Community Income [CI]; Infrastructure & Facility Development [IFD]; Employment Diversity [ED]; Accessibility [AC]; Community Purchasing Power [CPP]; Workforce Training [WT]; Economic Assistance Programs [EAP]; Local Economic Development [LED] |
| Social | Education Enhancement [EE]; Community Institutions [CI]; Youth Empowerment [YE]; Public Health Improvement [PHI]; Elderly Welfare & Support [EWS]; Community Deliberative Body [CDB]; Digital Information Access [DIA]; Mutual Cooperation & Solidarity [MCS]; Social & Moral Values [SMV]; Environmental Awareness & Responsibility [EAR]; Community Competitiveness [CC] |
| Environmental | Environmental Conservation & Protection [ECP]; Biodiversity Conservation [BC]; Green Space Expansion [GSE]; Soil Conservation [SC]; Drainage System Improvement [DSI]; Clean Water Access [CWA]; Seed Distribution & Reforestation [SDR]; Soil Quality Maintenance [SQM]; Coral Reef Conservation [CRC]; Groundwater Protection & Management [GPM]; Watershed Management [WM] |

The sustainability status index for each dimension is represented using radar charts through a multidimensional approach to determine the overall sustainability position of the Mandeh region.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Analysis Results for Land Cover

The land cover changes in the Mandeh region were prepared based on the determining factors for Land cover changes in the form of elevation, slope, distance from roads, economic centers, educational facilities, and health facilities (Akdeniz et al., 2023) from the total area of the whole area approx ±18000 ha (Raynaldo et al., 2020; Alhadi et al., 2023). With the development of marine tourism, development activities, and regional expansion there will be changes in land cover in this area. For more details, the land cover changes can be seen in **Table 2** and Map in **Figure 2** below.

**Table 2.**

**Analysis results for the prediction of land cover changes in the Mandeh region.**

| No | Land Cover | Area and Percentage (ha) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2020 | % | 2025 | % | 2030 | % |
| 1 | Water Bodies (WB) | 12036 | 67 | 11766 | 65 | 11776 | 65 |
| 2 | Secondary Forest (SF) | 2059 | 11 | 2025 | 11 | 1966 | 11 |
| 3 | Primary Forest (PF) | 871 | 5 | 815 | 5 | 609 | 3 |
| 4 | Mangroves (Ms) | 871 | 5 | 782 | 4 | 521 | 3 |
| 5 | Mixed Gardens (MG) | 760 | 4 | 620 | 3 | 504 | 3 |
| 6 | Plantation/Bush (P/B) | 550 | 3 | 558 | 3 | 606 | 3 |
| 7 | Rice Field (RF) | 359 | 2 | 361 | 2 | 360 | 2 |
| 8 | Palm Plantations (PP) | 291 | 2 | 282 | 2 | 426 | 2 |
| 9 | Built-up Land (BuL) | 202 | 1 | 791 | 4 | 1231 | 7 |
| **Total** | | **18000** | **100** | **18000** | **100** | **18000** | **100** |

*Source: Data analysis, 2024.*

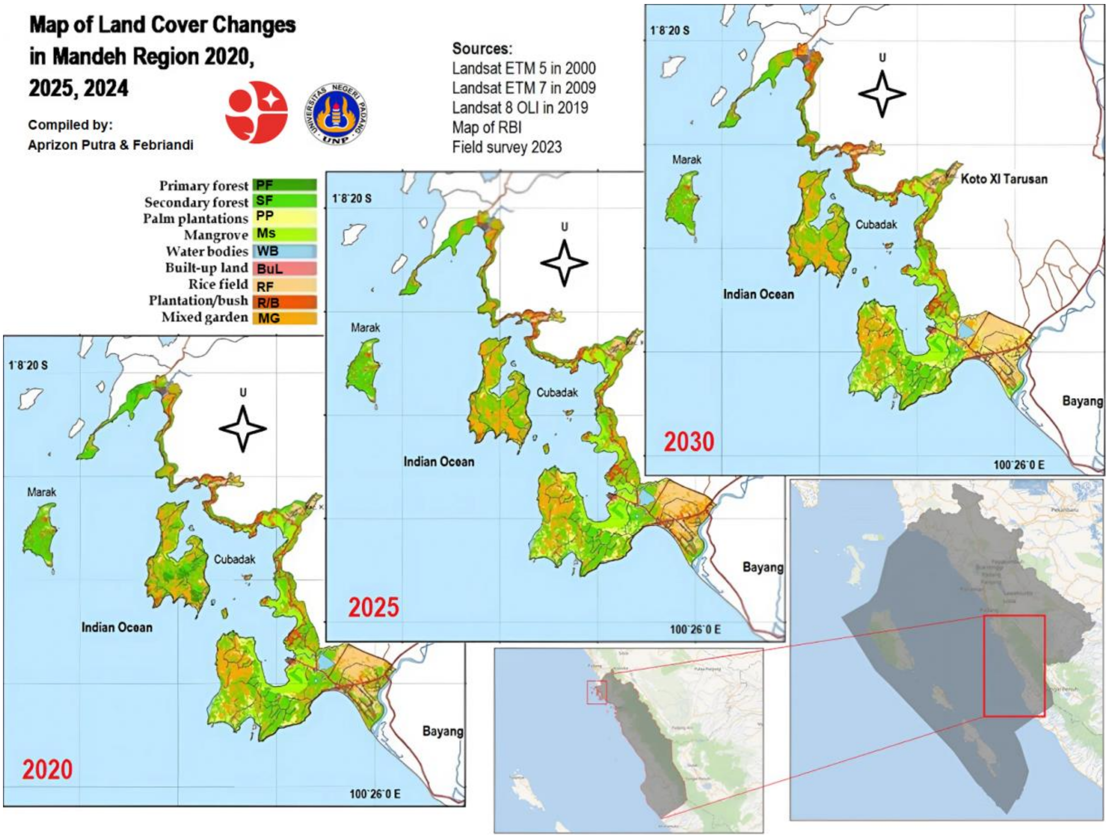


**Fig. 2.** Predicting map of land cover changes in Mandeh region for 2020, 2025 and 2030.

The predicted land cover changes in the Mandeh region for the period 2020–2030 are presented in Table 2, based on data derived from Landsat ETM 5 (2000), Landsat ETM+ 7 (2009), Landsat 8 OLI/TIRS (2019), and a reference map from the RBI. This analysis employs the Supervised Classification ML method, combined with the Markov Change Model and Markov Chain Cellular Automata, to examine the spatial dynamics of land cover transformation in the Mandeh region.

The findings indicate notable trends in three major land cover categories: 1) WB represents the dominant land cover, occupying 12036 ha (67%) in 2020. By 2025, this area is projected to decline slightly to 11766 ha (65%) and stabilize at 11776 ha (65%) by 2030. These fluctuations are attributed to natural factors such as sedimentation, erosion, and climate change, which gradually reshape coastal and aquatic ecosystems; 2) SF, which covered 2059 ha (11%) in 2020, is expected to decrease slightly to 2025 ha (11%) in 2025 and further decline to 1966 ha (11%) by 2030. This reduction is primarily caused by ongoing agricultural and plantation expansion, as well as infrastructure development, leading to the loss of forested areas; and 3) PF, which accounted for 871 ha (5%) in 2020, is projected to decrease to 815 ha (5%) in 2025 and continue declining sharply to 609 ha (3%) by 2030. This trend highlights the persistent threat of illegal logging and land conversion for plantation and settlement expansion. Other land cover types exhibit mixed trends over time. 1) Ms covered 871 ha (5%) in 2020 and is expected to shrink to 782 ha (4%) by 2025 and further decline to 521 ha (3%) in 2030. These changes reflect both conservation efforts and ongoing threats from human activities and climate change; 2) MG accounted for 760 ha (4%) in 2020 but are projected to decrease to 620 ha (3%) by 2025 and further to 504 ha (3%) in 2030. This decline is linked to the transformation of mixed-use lands into monoculture plantations, particularly palm oil estates, and increasing urban expansion; 3) P/B is expected to increase gradually, from 550 ha (3%) in 2020 to 558 ha (3%) in 2025 and 606 ha (3%) by 2030. This growth suggests that abandoned agricultural land is naturally regenerating into secondary vegetation; 4) RF will remain relatively stable, covering 359 ha (2%) in 2020, 361 ha (2%) in 2025, and 360 ha (2%) in 2030, with slight variations influenced by agricultural policies and climate conditions; 5) PP show a steady increase, from 291 ha (2%) in 2020 to 282 ha (2%) in 2025 and reaching 426 ha (2%) by 2030, largely driven by the growing global demand for palm oil; and 6) BuL, which occupied only 202 ha (1%) in 2020, is expected to expand significantly to 791 ha (4%) in 2025 and further to 1,231 ha (7%) in 2030. This reflects increased urbanization and infrastructure expansion driven by tourism development.

These findings highlight the need for better land cover planning and conservation efforts in the Mandeh region. The decline in forests and the expansion of plantations call for stricter regulations and reforestation programs. While BuL and Ms remain relatively stable, stronger policies are needed to protect them against climate change and human impact. Balancing economic growth with environmental sustainability is crucial for the long-term success of marine tourism.

The predicted land cover changes for 2030 indicate a significant increase in PP, which will expand to 426 ha (2%) of the total land in the Mandeh marine tourism region. This trend aligns with the rising global demand for palm oil, as noted by Murphy et al. (2021), who found that market-driven expansion often leads to aggressive plantation growth. Additionally, MG will decline to 504 ha (3%), reflecting the shift toward intensive monoculture systems. This trend supports the findings of Asante-Yeboah et al. (2024), who emphasized the role of land-use policies in altering agricultural landscapes. Moreover, P/B is expected to grow to 606 ha (3%) in 2030, aligning with Seto & Shepherd (2009), who observed that decreasing agricultural activity often results in the transformation of farmland into shrubland. Conversely, BuL is expected to expand to 1231 ha (7%), influenced by ongoing infrastructure development. This observation supports Halleux et al. (2012), who argued that policy enforcement and zoning regulations significantly impact urban expansion. Similarly, Ms are expected to decline to 521 ha (3%), despite conservation efforts. This trend corresponds with Spalding et al. (2014), who noted that while mangrove restoration programs contribute to long-term resilience, human activity remains a critical threat. PF will experience a severe decline, shrinking to just 609 ha (3%) of the total area by 2030, primarily due to land conversion for plantations and illegal deforestation. This trend is consistent with Nistor et al. (2019), who identified deforestation as a leading driver of forest loss. Similarly, SF will decrease to 1,966 ha (11%), a pattern observed by Huang et al. (2024), who linked forest shrinkage to agricultural expansion. RF will exhibit minimal changes, slightly declining to 360 ha (2%), a trend influenced by climate variability and irrigation policies, as discussed by Wang et al. (2023). Meanwhile, WB will remain relatively stable at 11776 ha (65%), with minor reductions due to sedimentation and coastal changes. These dynamics align with Vörösmarty et al. (2003), who examined similar patterns in Bukit Batu Kalang, where coastal processes and deforestation altered WB distribution.

### 3.2. Accuracy Test of Land Cover Changes

To assess the accuracy of land cover in the Mandeh region, a comprehensive accuracy test was conducted involving user accuracy, producer accuracy, and overall accuracy. The test results are presented in **Table 3**, which details the accuracy for the year 2020.

**Table 3.**

**Accuracy test of land cover 2020.**

| **Land Covers** | **Accuracy 2020** | | | | | | | | | **User Accuracy** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | |
| PF | 2 | | | | | | | | | 100.000 |
| SF | | 32 | | | | | | 2 | | 94.118 |
| PP | | | 3 | 1 | | | | | | 75.000 |
| Ms | | | | 8 | | | | | | 100.000 |
| WB | | | | | 2 | | | | | 100.000 |
| BuL | | | | | | 11 | | | 1 | 91.667 |
| RF | | | | 2 | | | 5 | 1 | | 62.500 |
| P/B | | | | 2 | | | | 2 | | 50.000 |
| MG | | | | | | | 1 | | 25 | 96.154 |
| **Producer Accuracy** | **100** | **100** | **100** | **72.7** | **100** | **110** | **83** | **40** | **96** | |
| | **2+32+3+8+2+11+5+2+25** | | | | | | | | | |
| | **90** | | | | | | | | | |

*Source: Data analysis, 2024.*

In **Table 3** above shows the user accuracy for various land cover categories. User accuracy measures the proportion of correctly classified instances out of all instances identified as a particular category. For 2020, the user accuracy of each category is as follows: 1) WB achieved a user accuracy of 100%; 2) SF achieved a user accuracy of 94.118%; 3) PP achieved a user accuracy of 75%; 4) Ms achieved a user accuracy of 100%; 5) WB achieved a user accuracy of 100%; 6) BuL land achieved a user accuracy of 91.667%; 7) RF achieved a user accuracy of 62.500%; 8) P/B achieved a user accuracy of 50%; and 9) MG achieved a user accuracy of 96.154%. Overall, for accuracy testing based on producer accuracy, the highest values are land cover changes of PF, Ms, and WB with a value of 100%. Meanwhile, overall accuracy value in 2020 was 90%, which is considered good and acceptable as a result of LM (Chowdhury, 2024). Next, **Table 4** below shows the user accuracy for various land cover categories in 2025.

**Table 4.**

**Accuracy test of land cover 2025.**

| **Land Covers** | **Accuracy 2025** | | | | | | | | | **Use Accuracy** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | |
| PF | 2 | | | | | | | | | 100.000 |
| SF | | 32 | | | | | | 2 | | 94.118 |
| PP | | | 3 | 1 | | | | | | 75.000 |
| Ms | | | | 6 | 2 | | | | | 75.000 |
| WB | | | | | 2 | | | | | 100.000 |
| BuL | | | | | | 11 | | | 1 | 91.667 |
| RF | | | | 2 | | | 5 | 1 | | 62.500 |
| P/B | | | | 2 | | | | 2 | | 50.000 |
| MG | | | | | | | 1 | | 25 | 96.154 |
| **Producer Accuracy** | **100** | **100** | **100** | **54.5** | **50** | **100** | **83** | **40** | **96** | |
| | **2+32+3+6+2+11+5+2+25** | | | | | | | | | |
| | **88** | | | | | | | | | |

*Source: Data analysis, 2024.*

For 2025, the user accuracy of each category is as follows: 1) WB achieved a user accuracy of 100%; 2) SF achieved a user accuracy of 94.118%; 3) PP achieved a user accuracy of 75%; 4) Ms achieved a user accuracy of 75%; 5) WB achieved a user accuracy of 100%; 6) BuL achieved a user accuracy of 91.667%; 7) RF achieved a user accuracy of 62.500%; 8) P/B achieved a user accuracy of 50%; and 9) MG achieved a user accuracy of 96.154%. Overall, for accuracy testing based on producer accuracy, the highest values are PF, WB, and MG with values of 100% and 96.154%. Meanwhile, overall accuracy value in 2025 is 88%, which is considered good and acceptable as a result of LM (Parashar et al., 2024). Next, **Table 5** below shows the user accuracy for various land cover categories in 2030.

**Table 5.**

**Accuracy test of land cover 2030.**

| | **Accuracy 2030** | | | | | | | | | **User Accuracy** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | |
| PF | 2 | | | | | | | | | 100.000 |
| SF | | 32 | | | | | | 2 | | 94.118 |
| PP | | | 3 | 1 | | | | | | 75.000 |
| Ms | | | | 6 | 2 | | | | | 75.000 |
| WB | | | | | 2 | | | | | 100.000 |
| BuL | | | | | | 10 | | | 2 | 83.333 |
| RF | | | | 2 | | | 5 | 1 | | 62.500 |
| P/B | | | | 2 | | | | 2 | | 50.000 |
| MG | | | | | | | 1 | | 25 | 96.154 |
| **Producer Accuracy** | **100** | **100** | **100** | **54.5** | **50** | **100** | **83** | **40** | **93** | |
| | **2+32+3+6+2+10+5+2+25** | | | | | | | | | |
| | **87** | | | | | | | | | |

*Source: Data analysis, 2024.*

User accuracy measures the proportion of correctly classified instances out of all instances identified as a particular category. For 2030, the user accuracy of each category is as follows: 1) WB achieved a user accuracy of 100%; 2) SF achieved a user accuracy of 94.118%; 3) PP achieved a user accuracy of 75%; 4) Ms achieved a user accuracy of 75%; 5) WB achieved a user accuracy of 100%; 6) BuL achieved a user accuracy of 83.333%; 7) RF achieved a user accuracy of 62.500%; 8) P/B achieved a user accuracy of 50%; and 9) MG achieved a user accuracy of 96.154%. Overall, the highest producer accuracy values in 2030 were for the PF, WB, and MG categories with values of 100% and 96.154%, respectively. The overall accuracy value in 2030 is 87%, which is considered good and acceptable as a result of LM (Tiwari et al., 2024).

### 3.3 Analysis Results for Sustainability Status

The Mandeh region is one of the most productive ecosystems. However, behind this potential, existing development can hurt natural resources. Human activities in utilizing natural resources, such as agriculture, fisheries, settlements, and tourism, often overlap, reducing the benefits or utility value of the ecosystem and threatening the sustainability of this area. So far, the Mandeh region has had a positive impact in the form of increasing people's income. The multi-purpose potential of the Mandeh region resources has also caused many parties to try to utilize it, resulting in conflict. To overcome this problem, a sustainability status is needed based on three dimensions: economy, social, and environmental. The results of the sustainability status analysis are described as follows.

#### *3.3.1. Economic Dimension*

The sustainability status in the Mandeh region, in terms of the economic dimension, includes [RI], [JO], [CI], [IFD], [ED], [AC], [CPP], [EAP], and [LED]. The leverage analysis for the economic dimension can be seen in **Figure 3** below.

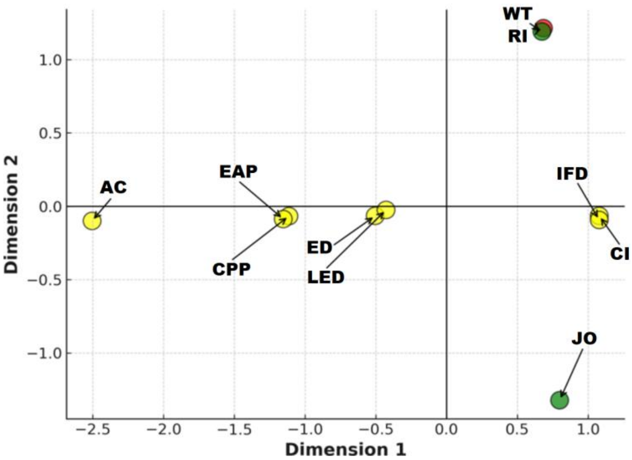


**Fig. 3**. Sustainability status model from the economic dimension.

In **Figure 3** shows that [CI] shares similarities with [RI], as they are positioned nearby within the same quadrant. Both [RI] and [CI] exhibit the highest values, recorded at 1.2137 and 1.1911, respectively. This indicates that, in terms of the economic dimension of marine tourism sustainability, priority should be given to enhancing [RI] and [CI]. To achieve this, improvements in [AC], [IFD], and [ED], as well as the expansion of [JO], are essential to support the growth of [RI] and [CI]. More details can be seen in **Figure 4** below.

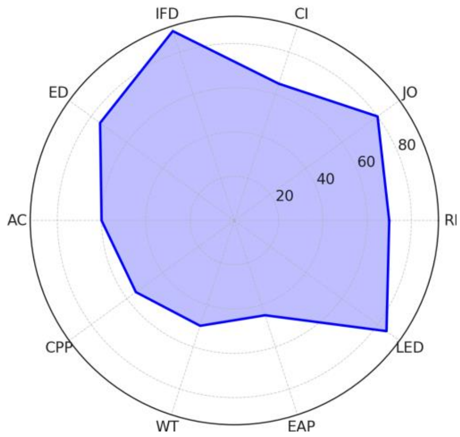


**Fig. 4**. Radar chart for sustainability value from economic dimension.

In **Figure 4** above shows that strengthening [RI] is essential for advancing sustainable tourism in the Mandeh region. A higher [RI] enables increased investments in [IFD], enhancing visitor comfort and encouraging longer stays. Another key focus is improving [CI], as a high [CI] value contributes to reducing land conversion, particularly in agricultural areas. This, in turn, helps prevent landslides and protects mangrove forests and coral reefs, preserving the region's natural beauty for future generations. [AC] improvements have significantly boosted tourist access to the Mandeh region. The completion of a 41-km road connecting Padang City (Bungus Teluk Kabung) to key locations such as Sungai Pisang, Sungai Pinang, Sungai Nyalo Mudiak Aia, Mandeh, and Carocok Anau in 2017 has transformed regional connectivity. Previously, access was primarily by sea, requiring connections through Nagari. With enhanced accessibility, new economic opportunities have emerged, including the development of lodgings and homestays along the route.

The expansion of accommodation facilities has generated diverse employment opportunities, such as restaurant staff, housekeeping, laundry services, security personnel, and water ride operators. The growth of inns, restaurants, and cafés contributes to economic expansion by creating jobs and increasing workforce participation or [ED].

Optimizing [RI] requires a multi-faceted approach, including: 1) Conducting door-to-door tax assessments by engaging all relevant departments within the regional revenue agency; 2) Enhancing administrative systems and procedures to improve service efficiency and facilitating effective supervision; 3) Aligning motor vehicle sales value regulations with national policies; 4) Drafting regional tax and levy regulations in accordance with central government policies; 5) Fostering cross-sector collaborations to explore additional revenue sources beyond traditional levies; 6) Maximizing motor vehicle tax revenues through public awareness campaigns; 7) Organizing Focus Group Discussions (FGD) with key stakeholders to develop effective RI optimization policies; and 8) Engaging expert consultants to identify and expand revenue sources beyond conventional taxation. The sustainability of the Mandeh marine tourism sector is evaluated using [RI], [JO], and [IFD] as key indicators. Orbelayn (2024) emphasized that increasing RI is crucial for infrastructure development and facility enhancements, which in turn boosts tourism appeal and encourages longer visitor stays. The construction of a 41-km road from Padang City to Mandeh has significantly improved accessibility, fostering new economic opportunities, particularly in the accommodation and restaurant sectors. These findings align with Seetanah (2011), who highlighted the critical role of infrastructure in stimulating tourism growth and generating employment [ED]. However, job creation must align with population growth to prevent rising unemployment rates.

*3.3.2. Social Dimension*

The sustainability status in the Mandeh region, in terms of the social dimension, includes [EE], [CI], [CDB], [PHI], [EWS], [MCS], [CS], [SMV], [EAR], and [CC]. The leverage analysis for the social dimension can be seen in the results in **Figure 5** below.

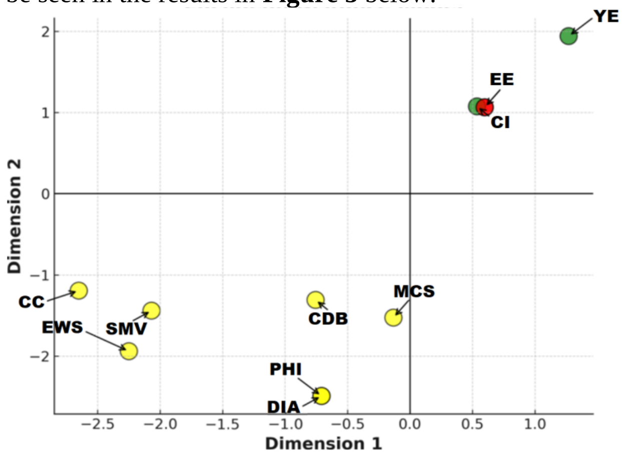


**Fig. 5**. Sustainability status model from the social dimension.

In **Figure 5** shows that [EE] shares similarities with [CI], as they are positioned nearby within the same quadrant. Both [EE] and [CI] exhibit the highest values, recorded at 1.0635 and 1.0747, respectively.

This indicates that, for the sustainability status of the Mandeh region to be maintained from a social perspective, priority should be given to enhancing [EE] and [CI]. Improving [EE] can be achieved by enhancing the quality of physical educational facilities, such as increasing the number of libraries and upgrading laboratory standards. Additionally, the provision of operational support, including expanding the number of schools, should also be considered to strengthen educational development. More details can be seen in **Figure 6** below.

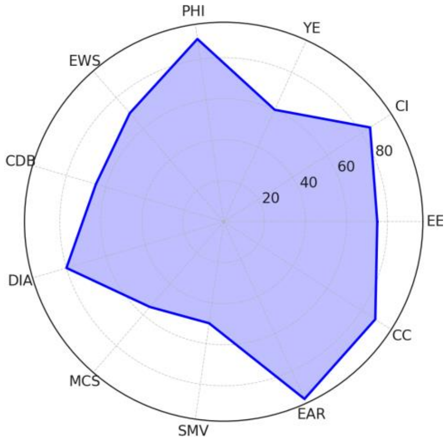


**Fig. 6**. Radar chart for sustainability value from social dimension.

In **Figure 6** shows that between [CI] and [EE], as they occupy a similar position within the same sub-dimension group. This highlights their significant role as key indicators of sustainable development in the Mandeh region. Meanwhile, [PHI], [EWS], [CDB], and [MCS] are positioned differently, yet remain within the same quadrant, indicating their relevance to similar aspects of social sustainability. In contrast, [CS], [EAR], and [SMV] are distinctly positioned, suggesting that they represent unique dimensions of social sustainability. Respondents perceive [CI] and [EE] as highly interconnected, reinforcing their importance in shaping long-term sustainability strategies. Consequently, these indicators serve as primary references for guiding sustainable development initiatives in the Mandeh region. The social sustainability status of the Mandeh region underscores the critical role of EE in education for sustainable development, particularly in environmental education. The primary objective is to increase public awareness regarding responsible natural resource management to mitigate environmental degradation linked to technological advancements. By fostering this understanding, local communities can develop a stronger commitment to sustainability principles, ensuring long-term natural resource conservation. Furthermore, improving [CI] levels is essential to maintaining a balanced approach between social and economic sustainability. Strengthening local economic conditions fosters a resilient and self-sufficient society in the Mandeh region, ensuring that social progress aligns with sustainable economic development. Social sustainability in the Mandeh marine tourism sector is evaluated through [EE] and [CI]. Omodan et al. (2024) emphasized the need for enhancing educational infrastructure, including libraries, laboratories, and sufficient operational support for schools. These efforts significantly contribute to education quality improvements and long-term social development. High values in [EE] and [CI] indicate their priority status in reinforcing social sustainability. This aligns with Winston et al. (2022), who highlighted that strengthening [EE] and [CI] fosters community solidarity and enhances local competitiveness or Community Competitiveness [CC].

### *3.3.3. Environmental Dimension*

The sustainability status in the Mandeh region, in terms of the environmental dimension, includes [ECP], [BC], [GOS], [GSE], [SC], [DSI], [CWA], [SQM], [CRC], [GPM], [WM], and [EF]. The leverage analysis for the environmental dimension can be seen in the results in **Figure 7** below. In **Figure 7** shows that [ECP] is closely related to [BC] due to their close positioning within the same quadrant. Both [ECP] and [BC] exhibit the highest scores, recorded at 1.388 and 1.389, respectively. This finding underscores the necessity of prioritizing [ECP] and [BC] in the environmental development of the Mandeh region. To effectively develop [ECP] and [BC], supportive efforts must be directed toward [CRC], [DSI], [SQM], [SC], and [CWA]. Additionally, achieving a sustainable Mandeh region requires a strong emphasis on [CWA], as ensuring the availability of clean water plays a critical role in enhancing community welfare.

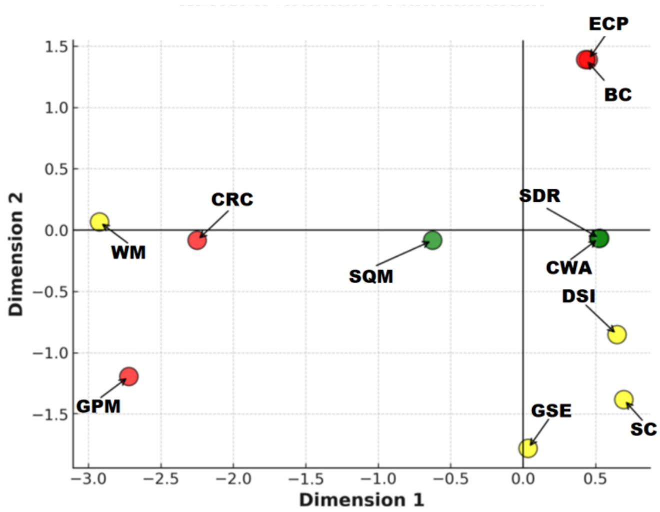


**Fig. 7**. Sustainability status model from the environmental dimension.

Furthermore, attention should be given to [GSE] as an essential component of sustainability. This can be realized through the establishment of elongated [GSE] areas or pathways that remain predominantly open and free from constructed buildings, ensuring environmental balance and long-term ecological benefits. More details can be seen in **Figure 8** below.

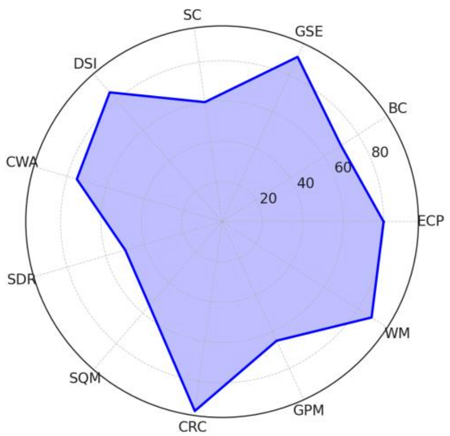


**Fig. 8.** Radar chart for sustainability value from environmental dimension.

In **Figure 8** shows that [ECP] and [BC] are closely linked to the conservation of [CRC]. To ensure [CRC] remains sustainable, several key environmental factors must be considered, including temperature, salinity, sunlight availability, ocean currents, and sedimentation levels. Coral reefs thrive at 23–25°C (Putra et al., 2023) and at salinity levels ranging from 30–35% (Ding et al., 2022). Additionally, sunlight is essential for coral photosynthesis, with optimal growth occurring at depths shallower than 25 meters (Kahng et al., 2019). While ocean currents provide essential nutrients for coral ecosystems, excessive sedimentation can severely hinder coral growth and survival. Furthermore, [SQM] plays a crucial role in sustaining [ECP] and [BC], as soil supports plant growth and serves as a foundation for human activities. To enhance environmental sustainability in the Mandeh region, conservation efforts should promote eco-friendly industrial practices, including utilizing recycled materials, preserving [GSE], and implementing sustainable land management strategies.

## 4. CONCLUSIONS

The prediction analysis for land cover changes in the Mandeh marine tourism region until 2030 indicates a notable trend in land conversion. WB remain the dominant land cover, decreasing slightly from 67% in 2020 to 65% in 2030, influenced by sedimentation, erosion, and climate change. SF, which covered 11% in 2020, are expected to decline slightly to 11% in 2025 and 11% in 2030, primarily due to agriculture and plantation expansion. PF will decrease significantly from 5% in 2020 to just 3% in 2030, driven by illegal logging and land conversion for plantations and settlements. Ms will decline from 5% to 3%, necessitating enhanced conservation efforts. MG are projected to shrink from 4% in 2020 to 3% in 2030, reflecting a shift toward monoculture plantations and increasing urban expansion. Meanwhile, BuL is expected to grow significantly from just 1% in 2020 to 7% in 2030, indicating intensified urban development driven by tourism infrastructure expansion. PP will expand steadily, increasing from 2% in 2020 to 2% in 2025 and reaching 2% by 2030, aligning with the global demand for palm oil. RF remain relatively stable at 2%, with slight variations influenced by agricultural policies and climate conditions.

Accuracy assessment confirms the high reliability of the model, with user accuracy for PF, Ms, and WB reaching 100% in 2020, followed by a slight decline in 2025 and 2030. Despite this, overall accuracy remained above 87%, ensuring strong data validity for future planning.

The sustainability status of marine tourism in Mandeh highlights key aspects from 1) Economic sustainability, increasing [RI] is essential for infrastructure development, enhancing tourism appeal, and encouraging longer visitor stays. The completion of a 41-km road from Padang City to Mandeh has opened new economic opportunities, particularly in accommodations and restaurants.

However, job creation must align with workforce growth to prevent rising unemployment rates. ED and [JO] must be optimized to ensure sustainable employment expansion; 2) Social sustainability, [EE] and [CI] play a critical role in developing human capital. Improving educational infrastructure, such as libraries and laboratories, can increase education quality and social development. Additionally, [PHI] and [MCS] should be strengthened to foster community resilience and social competitiveness [CC]; and 3) Environmental sustainability, [ECP], [BC], and [WM] highlight the need for conservation to protect marine ecosystems. Ensuring optimal coral reef conditions, minimizing sedimentation, and implementing effective waste management strategies is crucial. Additionally, adopting environmentally friendly practices, including recycling, [GSE], and [DSI], supports long-term environmental sustainability. Considering these land cover changes, the RSP must address the decline in SF and the expansion of plantations and built-up areas.

Policies supporting sustainable development, including designated green zones and protective regulations, should be prioritized. Infrastructure planning must minimize ecological impact while fostering economic growth. Local governments must integrate natural resource management with economic policies to maintain a balance between conservation and development. Establishing clear land cover boundaries, implementing conservation programs, and enforcing sustainability regulations are critical. By incorporating ecological considerations into planning, the RSP can effectively harmonize economic growth with environmental protection, ensuring the long-term viability of the Mandeh marine tourism region.

## ACKNOWLEDGEMENTS

We sincerely appreciate the generous support of the local government of Pesisir Selatan Regency, West Sumatra Province, particularly for providing access to essential data and field assistance. Their collaboration and dedication have been instrumental in the successful completion of this research. We also extend our heartfelt gratitude to everyone who contributed to this research your support and cooperation are truly valued.

## REFERENCES

Alhadi, Z., Sasmita, S., Yulfa, A., Fatimah, S., Syafrini, D., Maani, K. D., & Riandini, O. (2023). The Coping Strategies Patterns Based on Local Wisdom and Resilience Capital in Facing Natural Disaster Risk in Nagari Mandeh, Indonesia. *International Journal of Sustainable Development & Planning*, 18(1). 315-325. DOI : 10.18280/ijsdp.180133

Arif, M., Sengupta, S., Mohinuddin, S. K., & Gupta, K. (2023). Dynamics of land use and land cover change in peri urban area of Burdwan city, India: a remote sensing and GIS based approach. *GeoJournal*, *88*(4), 4189-4213, DOI: 10.1007/s10708-023-10860-3

Akdeniz, H. B., Sag, N. S., & Inam, S. (2023). Analysis of land use/land cover changes and prediction of future changes with land change modeler: Case of Belek, Turkey. *Environmental Monitoring and Assessment*, *195*(1), 135, DOI: 10.1007/s10661-022-10746-w

Ansharullah, A., & Natasha, H. (2020) Mandeh Special Economic Area (Kek) as The Model of Sharia Tourism Development in West Sumatra Province. *Eklektik: Jurnal Pendidikan Ekonomi dan Kewirausahaan*, *3*(2), 116-124. DOI: 10.24014/ekl.v3i2.11809

Asante-Yeboah, E., Koo, H. M., Ros-Tonen, M. A. F., Sieber, S., & Fürst, C. (2024). Participatory and spatially explicit assessment to envision the future of land-use/land-cover change scenarios on selected ecosystem services in Southwestern Ghana. *Environmental Management*, 74, 94–113, DOI: 10.1007/s00267-024-01943-z

Bahar, A. (2023). Tourism sustainability is a big problem in the development of marine tourism in Indonesia. *Routledge Handbook of Trends and Issues in Tourism Sustainability, Planning and Development, Management, and Technology*. 103-110.

Bakus, G. J. (2007). *Quantitative analysis of marine biological communities: field biology and environment*. John Wiley & Sons, DOI: 10.1016/j.jhazmat.2007.02.064

Benito, P. R., Cuevas, J. A., de la Parra, R. B., Prieto, F., Del Barrio, J. G., & de Zavala Gironés, M. Á. (2010). Land use change in a Mediterranean metropolitan region and its periphery: assessment of conservation policies through CORINE Land Cover data and Markov models. *Forest Systems*, *19*(3), 315-328, DOI: 10.5424/fs/2010193-8604

Binarti, F., & Santoso, A. J. (2023). Identifying climate change vulnerability based on land cover indicators: A case study in Surabaya, Indonesia. *Geographia Technica, 18*(1), 71–84, DOI: 10.21163/GT_2023.181.06

Brown, G., Strickland-Munro, J., Kobryn, H., & Moore, S. A. (2017). Mixed methods participatory GIS: An evaluation of the validity of qualitative and quantitative mapping methods. *Applied geography*, *79*, 153-166, DOI: 10.1016/j.apgeog.2016.12.015

Chowdhury, M. S. (2024). Comparison of accuracy and reliability of random forest, support vector machine, artificial neural network and maximum likelihood method in land use/cover classification of urban setting. *Environmental Challenges, 14,* Article 100800. DOI: 10.1016/j.envc.2023.100800

Costea, G., & Haidu, I. (2010). Detection of recent spatial changes regarding land use in small basins from the Apuseni Natural Park. *Geographia Technica, 2*, 11–17.

Cuevas-Wizner, R., Ledda, A., Martín, B., Ortega, E., Calia, G., & De Montis, A. (2024). Mainstreaming adaptation to climate changes: A comparison between Sardinia, Italy, and Valencia, Spain. *Sustainability, 16*(16), 7099, DOI: 10.3390/su16167099

Czapla-Myers, J. S., Thome, K. J., Anderson, N. J., Leigh, L. M., Pinto, C. T., & Wenny, B. N. (2024). The ground-based absolute radiometric calibration of the Landsat 9 operational land imager. *Remote Sensing, 16*(6), 1101, DOI: 10.3390/rs16061101

Darem, A. A., Alhashmi, A. A., Almadani, A. M., Alanazi, A. K., & Sutantra, G. A. (2023). Development of a map for land use and land cover classification of the Northern Border Region using remote sensing and GIS. *The Egyptian Journal of Remote Sensing and Space Science*, *26*(2), 341-350, DOI: 10.1016/j.ejrs.2023.04.005

Dash, P., Sanders, S. L., Parajuli, P., & Ouyang, Y. (2023). Improving the accuracy of land use and land cover classification of landsat data in an agricultural watershed. *Remote Sensing*, *15*(16), 4020, DOI: 10.3390/rs15164020

Ding, D. S., Patel, A. K., Singhania, R. R., Chen, C. W., & Dong, C. D. (2022). Effects of temperature and salinity on growth, metabolism and digestive enzymes synthesis of goniopora columna. *Biology*, *11*(3), 436, DOI: 10.3390/biology11030436

Duggan, J., Clement, S., Cvitanovic, C., & Van Putten, I. (2024). Incorporating sense of place into the management of social-ecological systems: The researchers’ perspectives. *Plos one*, *19*(9), e0308726, DOI: 10.1371/journal.pone.0308726

Fatimah, S., Syafrini, D., Wasino, & Zainul, R. (2021). Rendang lokan: history, symbol of cultural identity, and food adaptation of Minangkabau tribe in West Sumatra, Indonesia. *Journal of Ethnic Foods*, *8 (12)*, 1-10. DOI: 10.1186/s42779-021-00088-2

Fauzi, A., & Anna, S. (2002). Evaluasi status keberlanjutan pembangunan perikanan: aplikasi pendekatan Rapfish. *Jurnal Jurusan sosial ekonomi perikanan FPIK IPB*, *4*(3), 43-55.

Furtună, P., Haidu, I., Alexe, M., & Holobâcă, I. (2016). Change detection in the Cluj forest district using remote sensing and GIS application. *Environmental Engineering and Management Journal, 15*(6), 1361–1367. DOI: 10.30638/eemj.2016.146

Halleux, J.-M., Marcinczak, S., & van der Krabben, E. (2012). The adaptive efficiency of land use planning measured by the control of urban sprawl: The cases of the Netherlands, Belgium, and Poland. *Land Use Policy*, 29(4), 887–898, DOI: 10.1016/j.landusepol.2012.01.008

Haris, N. A., Kusuma, S. S., Arjasakusuma, S., & Wicaksono, P. (2021). Comparison of Sentinel-2 and multitemporal Sentinel-1 SAR imagery for mapping aquaculture pond distribution in the coastal region of Brebes Regency, Central Java, Indonesia. *Geographia Technica, 16*(Special Issue), 128–137, DOI: 10.21163/GT_2021.163.10

Hermon, D. I., Putra, A., & Oktorie, O. (2020). Spatial analysis of tsunami vulnerability zones as a basic concept of coastal disaster mitigation in development planning of Pariaman City. *Journal of Advanced Research in Dynamical and Control Systems*, *12(07-Special Issue)*, 681-690, DOI: 10.5373/JARDCS/V12SP7/20202158

Hermon, D., Gusman, M., Putra, A., & Dewata, I. (2022). Value estimating of the sedimentation rate at the shipwreck sites (MV Boelongan Nederland) the Mandeh Bay Region-Pesisir Selatan Regency. *IOP Conference Series: Earth and Environmental Science*. 967(1), 012007, DOI: 10.1088/1755-1315/967/1/012007

Hidayah, I., Januar, H. I., & Humaida, N. (2024). Habitat suitability model of future coral reef region in the Halmahera Waters under the projection of environmental pressures from future climate change and coastal pollution. *IOP Conference Series: Earth and Environmental Science*, 1328(1), 012006, DOI: 10.1088/1755-1315/1328/1/012006

Huang, W., Hashimoto, S., Yoshida, T., Saito, O., & Meraj, G. (2024). Understanding Japan's land-use dynamics between 1987 and 2050 using land accounting and scenario analysis. *Sustainability Science, 19*, 1561–1577, DOI: 10.1007/s11625-024-01517-2

Hussain, S., Mubeen, M., Nasim, W., Mumtaz, F., Abdo, H. G., Mostafazadeh, R., & Fahad, S. (2024). Assessment of future prediction of urban growth and climate change in district Multan, Pakistan using CA-Markov method. *Urban Climate*, *53*, 101766, DOI: 10.1016/j.uclim.2023.101766

Jinzhu, G., An, T., Zhang, K., & Zhao, R. (2024). Development and reform of marine spatial planning in China under the new territorial spatial planning system. *Marine Development*, 2(2), DOI:10.1007/s44312-024-00014-5

Kahng, S. E., Akkaynak, D., Shlesinger, T., Hochberg, E. J., Wiedenmann, J., Tamir, R., & Tchernov, D. (2019). Light, temperature, photosynthesis, heterotrophy, and the lower depth limits of mesophotic coral ecosystems. *Mesophotic coral ecosystems*, 801-828, DOI: 10.1007/978-3-319-92735-0_42

Lilimu, M. D. (2023). Application of Remote Sensing and GIS in Monitoring Land Use and Land Cover Change in the Nandoni Dam Basin. [*Dissertation*] University of Cape Town

Murphy, D. J., Goggin, K., & Paterson, R. R. M. (2021). Oil palm in the 2020s and beyond: challenges and solutions. *CABI agriculture and bioscience*, *2*, 1-22, DOI: 10.1186/s43170-021-00058-3

Nistor, M.M., Rahardjo, H., & Satyanaga, A. (2019). Development assessment of the Singapore land: A GIS spatial-temporal approach. *Geographia Technica*, 14(2), 60–73, DOI: 10.21163/GT_2019.142.06

Omodan, B. I. (2024). Redefining university infrastructure for the 21st century: An interplay between physical assets and digital evolution. Journal of Infrastructure, Policy and Development, 8(4), 3468, DOI: 10.24294/jipd.v8i4.3468

Orbelayn, G. (2024). Socio-economic challenges for the urban ecosystem: Complex model of smart tourism and infrastructure. *SocioEconomic Challenges*, *8*(4), 146-160, DOI: 10.61093/sec.8(4).146-160.2024

Papageorgiou, M. (2016). Coastal and marine tourism: A challenging factor in Marine Spatial Planning. *Ocean & Coastal Management*, *129*, 44-48, DOI: 10.1016/j.ocecoaman.2016.05.006

Parashar, D., Kumar, A., Palni, S., Pandey, A., & Singh, A. (2024). Use of machine learning-based classification algorithms in the monitoring of Land Use and Land Cover practices in a hilly terrain. *Environmental Monitoring and Assessment*, *196*(1), Article 8. DOI: 10.1007/s10661-023-12131-7

Paul, S. S., Li, J., Wheate, R., & Li, Y. (2018). Application of object oriented image classification and Markov chain modeling for land use and land cover change analysis. *Journal of Environmental Informatics*, *31*(1), 30-40, DOI: 10.3808/jei.201700368

Prarikeslan, W., Syah, N., Barlian, E., Suasti, Y., & Putra, A. (2020). A potential locations of marine tourism in pasumpahan island, Padang City-Indonesia. *International Journal of GEOMATE, 19*(72), 123-130, DOI: 10.21660/2020.72.ICGeo5

Putra, A., Triyatno., Darwis, R., Dewata, I., Tanto, T. A., Mustapha, M. A., Razi, P., & Zainul, R. (2023). Suitability of Mangrove Ecosystems as a Protected Zone Based on Land-Use Changes. *Physical Oceanography*, *30*(6), 866-881.

Putra, A., Dewata, I., Hermon, D., Barlian, E., Umar, G., Widodo, T., & Damanhuri, H. (2023). Activity Recommendations Based on an Environmental Approach in Zoning of Marine Protected Areas (MAPS) Pariaman City-Indonesia. *EnvironmentAsia*, *16*(3), 57-67, DOI: 10.14456/ea.2023.35

Putra, A., Hermon, D., Yulius, A., Prarikeslan, W., Syarief, A., Ridwan, N., Arifin, T., Febriandi, F., Damanhuri, H., Widodo, T., & Dermawan, A. (2024). Assessment of seawater quality and environmental sustainability for shipwreck diving tourism: A case study of MV Boelongan Nederland in Mandeh Bay, Indonesia. *Geography,Environment,Sustainability*, *17*(4), 171–182, DOI: 10.24057/2071-9388-2024-3469

Pons, X., Pesquer, L., Cristóbal, J., & González-Guerrero, O. (2014). Automatic and improved radiometric correction of Landsat imagery using reference values from MODIS surface reflectance images. *International Journal of Applied Earth Observation and Geoinformation, 33*, 243–254, DOI: 10.1016/j.jag.2014.06.002

Raynaldo, A., Mukhtar, E., & Novarino, W. (2020). Mapping and change analysis of mangrove forest by using Landsat imagery in Mandeh Bay, West Sumatra, Indonesia. *Aquaculture, Aquarium, Conservation & Legislation*, *13*(4), 2144-2151.

Seetanah, B., Juwaheer, T. D., Lamport, M. J., Rojid, S., Sannassee, R. V., & Subadar, A. U. (2011). Does infrastructure matter in tourism development?. *University of Mauritius research journal, 17*, 89-108, DOI: 10.4314/umrj.v17i1.70731

Seto, K. C., & Shepherd, J. M. (2009). Global urban land-use trends and climate impacts. *Current Opinion in Environmental Sustainability*, 1(1), 89–95, DOI: 10.1016/j.cosust.2009.07.012

Smith, H. D., Maes, F., Stojanovic, T. A., & Ballinger, R. C. (2011). The integration of land and marine spatial planning. *Journal of Coastal Conservation*, *15*, 291-303, DOI: 10.1007/s11852-010-0098-z

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., & Beck, M. W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean & Coastal Management*, 90, 50–57, DOI: 10.1016/j.ocecoaman.2013.09.007

Syam, A. (2018). Policy Model of Physical Changes in The Environment of Mandeh Area From 2008-2018. *Sumatra Journal of Disaster, Geography and Geography Education*, *2*(2), 9-15. DOI: 10.24036/sjdgge.v2i2.169

Tiwari, A., Kira, O., Bamah, J., Boneh, H., & Karnieli, A. (2024). Multi-Sensor Classification Framework of Urban Vegetation for Improving Ecological Services Management. *Remote Sensing, 16*(6), Article 1110. DOI: 10.3390/rs16061110

Vörösmarty, C. J., Meybeck, M., Fekete, B., Sharma, K., Green, P., & Syvitski, J. P. M. (2003). Anthropogenic sediment retention: Major global impact from registered river impoundments. *Global and Planetary Change, 39*(1–2), 169–190, DOI: 10.1016/S0921-8181(03)00023-7

Wang, J., Yin, X., Liu, S., & Wang, D. (2023). Spatiotemporal change and prediction of land use in Manasi region based on deep learning. *Environmental Science and Pollution Research*, *30*(34), 82780-82794, DOI: 10.1007/s11356-023-27826-0

Watt-Pringle, R., Razak, T. B., Jompa, J., Ambo-Rappe, R., Kostaman, A. N., & Smith, D. J. (2024). Coral reef restoration in Indonesia: Lessons learnt from the world's largest coral restoration nation. *Biodiversity and Conservation, 33*, 2675–2707, DOI: 10.1007/s10531-024-02897-8

Wilis, R., Nugroho, S., Barlian, E., & Syah, N. (2020). Characteristics of Outdoor Thermal Comfort Index (OCTI) at Mandeh Tourism Site. *International Journal of GEOMATE*, *19*(73), 250-256, DOI: 10.21660/2020.73.ICGeo47

Winston, N. (2022). Sustainable community development: Integrating social and environmental sustainability for sustainable housing and communities. *Sustainable Development,30*(1), 191–202,DOI: 10.1002/sd.2238

Zhang, Z., Hörmann, G., Huang, J., & Fohrer, N. (2023). A random forest-based CA-Markov Model to Examine the Dynamics of Land Use/Cover Change Aided with remote sensing and GIS. *Remote Sensing*, *15*(8), 2128, DOI: 10.3390/rs15082128

Zakaria, I. J., Wulandari, A., & Febria, F. A. (2021). Diseases and health disturbances on scleractinian corals in the West Sumatra Sea, Indian Ocean. *Aquaculture, Aquarium, Conservation & Legislation*, *14*(1), 462-477.